

Updated results from maximally twisted mass lattice QCD at the physical point

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Introduction

Action

- Lattice 2013: introduced twisted mass action with clover term

[Frezzotti, Grassi, Sint, Weisz, 2000; Frezzotti, Rossi; 2004]

$$S = \beta \sum_{x;P} \left[b_0 \left\{ 1 - \frac{1}{3} \text{Re} \text{Tr} P^{1 \times 1}(x) \right\} + b_1 \left\{ 1 - \frac{1}{3} \text{Re} \text{Tr} P^{1 \times 2}(x) \right\} \right] \\ + \sum_x \bar{\chi}(x) \left[D_W(U) + m_0 + i\mu\gamma^5\tau^3 + \frac{i}{4}C_{SW}\sigma^{\mu\nu}\mathcal{F}^{\mu\nu}(U) \right] \chi(x)$$

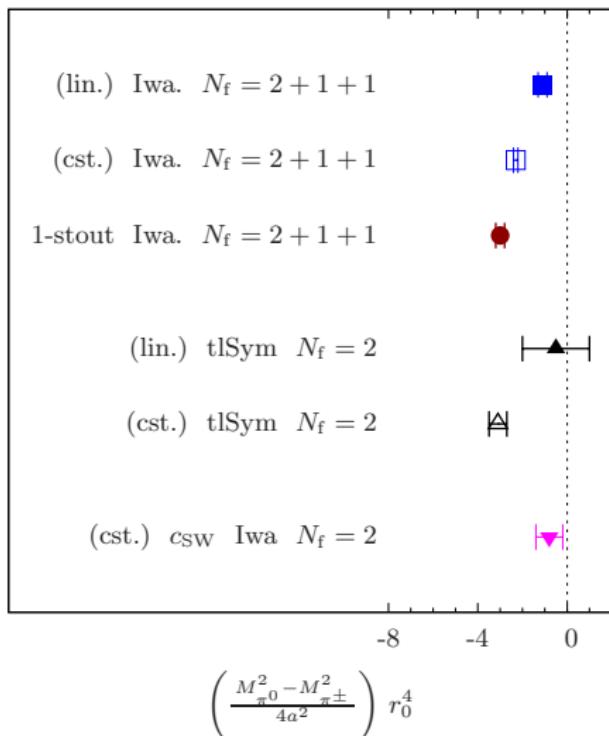
- $N_f = 2$
- $b_0 = 1 - 8b_1, b_1 = -0.331$ [Iwasaki; 1983]
- $C_{SW} = 1.57551$ from Padé fit of CP-PACS data

[Aoki et al.; Phys.Rev. D73 (2006) 034501]

- Automatic $\mathcal{O}(a)$ improvement at maximal twist
- Clover term to stabilize simulations, control certain $\mathcal{O}(a^2)$ effects
- Important: clover term does not spoil $\mathcal{O}(a)$ improvement!

Isospin Breaking

Pion

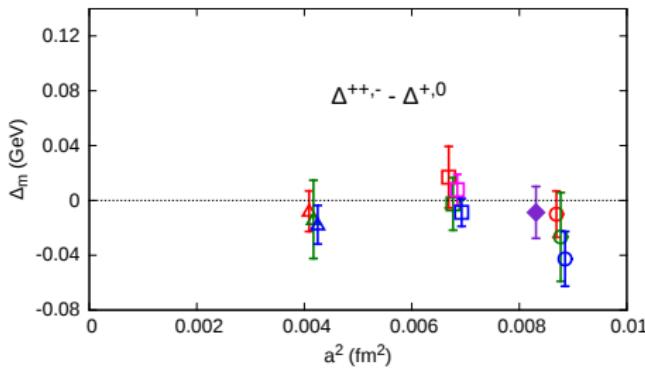


lin./cst. extrapolation to physical point

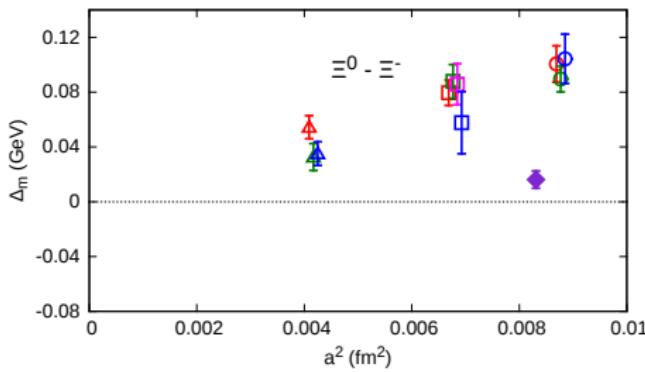
- In the past: affected stability of simulations and forced $m_\pi^\pm \gtrsim 230$ MeV
- Shown here in units allowing comparison to c_2 LEC [JHEP 1305 (2013) 038]
- In physical units $\sim 20(20)$ MeV at $a \sim 0.091(1)$ fm
- confirms expectation from stable simulations
- Note: computed on $24^3 \cdot 48$ lattice and $m_\pi^\pm \sim 340$ MeV, currently no variance reduction implemented

Isospin Breaking

Baryon sector



○ Old $N_f = 2 + 1 + 1$
◆ New $N_f = 2$ tm-clover
preliminary



- For Δ , isospin splitting still compatible with 0
- For Ξ , indications that isospin splitting reduced markedly
 - For old $N_f = 2 + 1 + 1$, note linear scaling with a^2
- $N_f = 2 + 1 + 1$ spectrum with old action [arXiv:1406.4310]

Strange/Charm Quark Masses

Mass ratios

Lattice 2013

- $\mu_s/\mu_l = 27.46(44)$ (FLAG) [arXiv:1310.8555]
 - $\mu_c/\mu_s = 11.85(16)$ (HPQCD) [Phys. Rev. Lett. 104, 132003 (2010)]
⇒ ratios of decay constants consistent with PDG/FLAG values. But:
 - Not impressive - ratios f_{PS}^b/f_{PS}^a have large uncertainties → with 2013 statistics, quite insensitive to heavy quark masses
 - FLAG/HPQCD ratios → large uncertainties in quark masses
 - ▶ Ability to tune charm mass important for $N_f = 2 + 1 + 1!$
 - Can we do better?
-
- Because we are at the physical point, try to match m_K/m_π and m_D/m_π directly using linear interpolations
⇒ Check consistency with FLAG/HPQCD

Strange/Charm Quark Masses

Summary

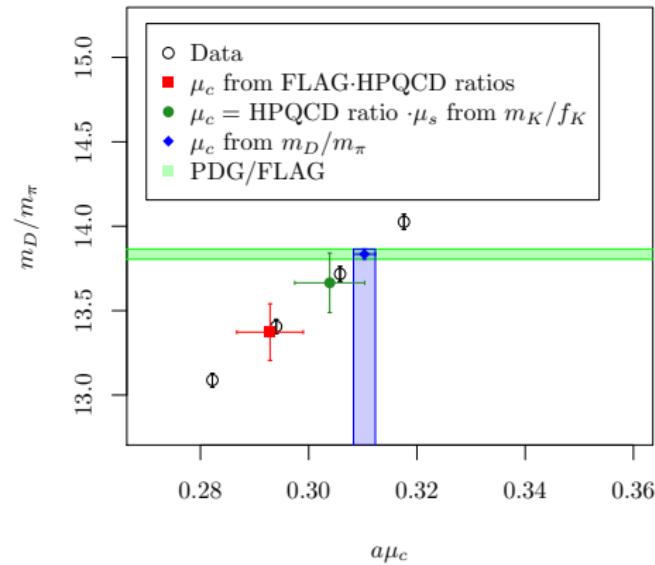
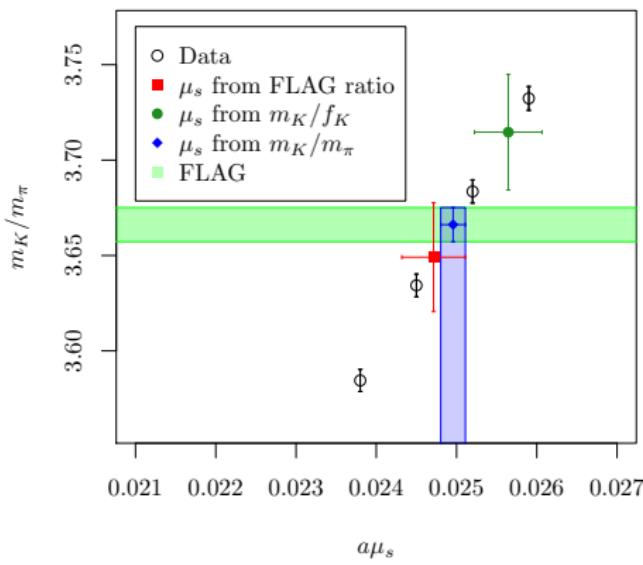
L/a	48
T/a	96
β	2.10
b_1	-0.331
κ	0.13729
$a\mu_I$	9×10^{-4}
C_{SW}	1.57551
N_{traj}	> 5000
$\langle P \rangle$	0.603526(4)
$\tau_{int}(\langle P \rangle)$	14.0(5.0)
am_{PCAC}	$8(1) \times 10^{-5}$
$m_\pi L$	3.00(2)
a	0.091(1) fm ^a

^anote: no FS corrections for f_π ,
but same result from nucleon mass

- linearly interpolate m_K/m_π and m_D/m_π to physical values
 - 1D/2D lin. model for other quantities to see effect of μ_s , μ_c quark mass tuning
- ⇒ Discrepancies will provide hints of FS / discretisation artefacts
- Analysis based on:
 - ▶ 675 measurements
 - ▶ Osterwalder-Seiler valence quarks
 - ▶ fuzzed and local interpolating fields
 - ▶ timeslice sources with spin dilution
 - ▶ 16 mass combinations
 - ▶ $\mu_s/\mu_I \in [26.4, 28.8]$
 - ▶ $\mu_c/\mu_s \in [10.9, 13.3]$

Strange/Charm Quark Masses

matching m_K/m_π and m_D/m_π



$$\frac{m_s}{m_{ud}} = 27.73(17)$$

$$\frac{m_c}{m_{ud}} = 344.8(2.2)$$

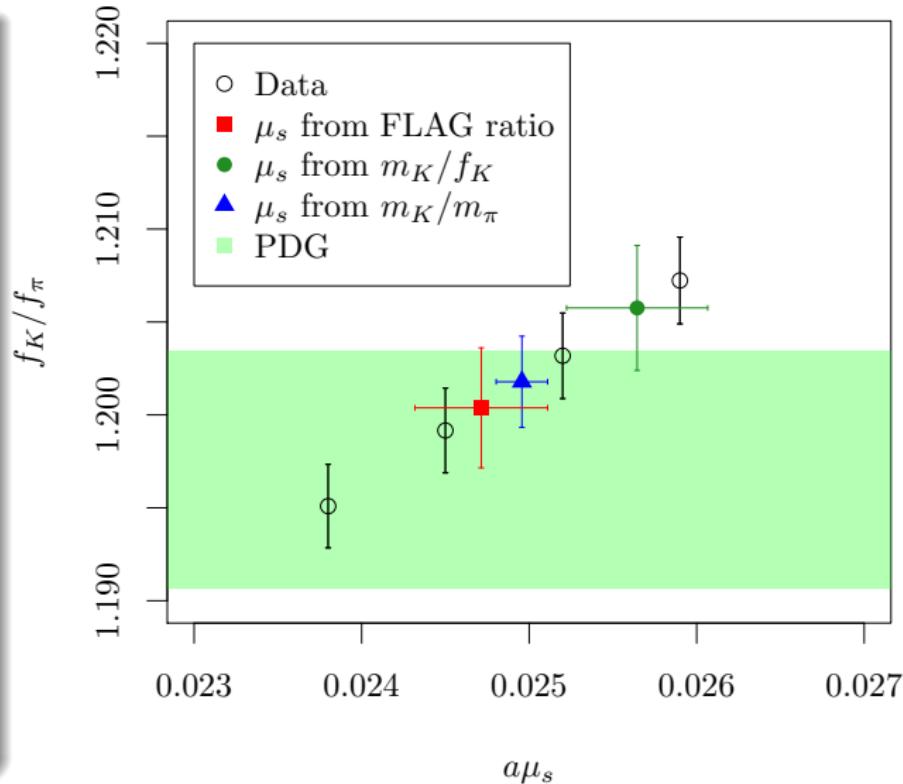
$$\frac{m_c}{m_s} = 12.43(11)$$

Strange/Charm Quark Masses

Quark mass ratios in practice

$$\frac{f_K}{f_\pi}$$

- only very mild dependence on $a\mu_s$ tuning at physical point
- FLAG ratio and m_K/m_π consistent
- $a\mu_s$ from m_K/f_K comes with large uncertainty
- note: these are %‐level effects!

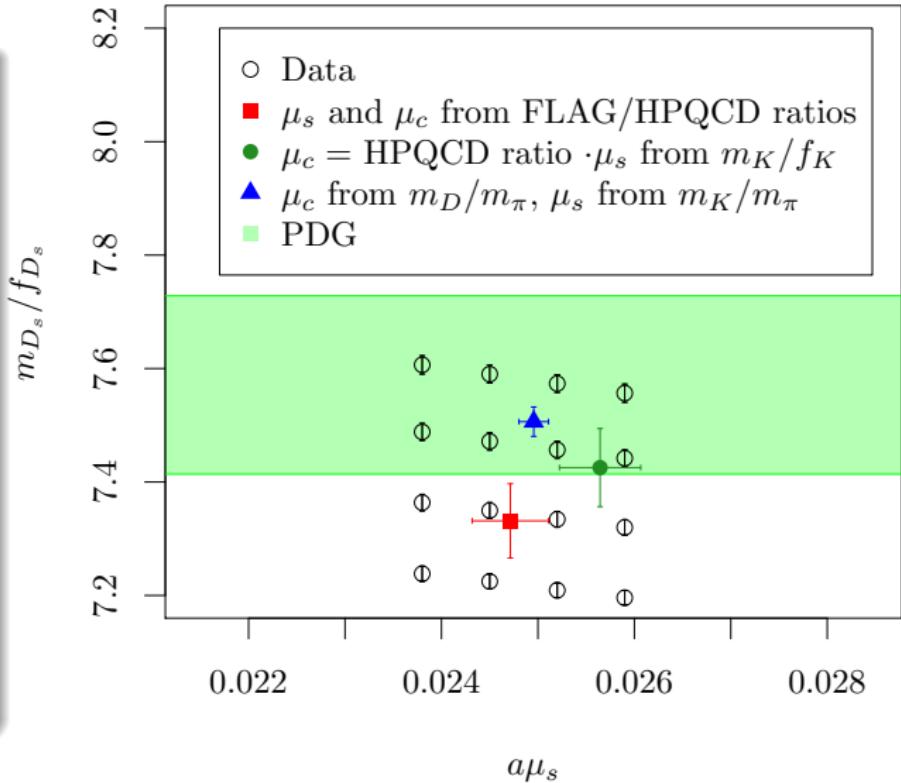


Strange/Charm Quark Masses

Quark mass ratios in practice

$$\frac{m_{D_s}}{f_{D_s}}$$

- seems to prefer heavier $a\mu_c$ from m_D/m_π , but need to keep in mind $\mathcal{O}(a^2)$ artefacts
- from lattice $m_{D_s}/f_{D_s} = 7.9(2)$ would seem to prefer even larger $a\mu_c$

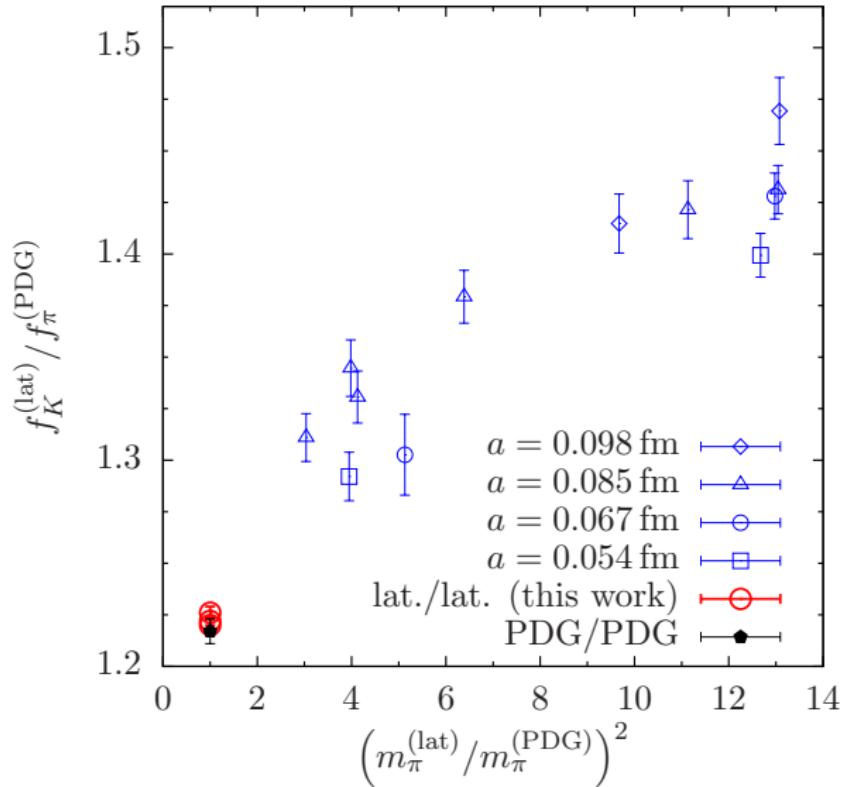


Pseudoscalar Meson Decay Constants

Kaon decay constant

$$\frac{f_K}{f_\pi}$$

- old $N_f = 2$
- new $N_f = 2$
tm-clover
- as shown
previously, quite
insensitive to
 $\sim 10\%$ changes
in $a\mu_s$
- but from old
data, $\mathcal{O}(a^2)$
effects not
negligible!

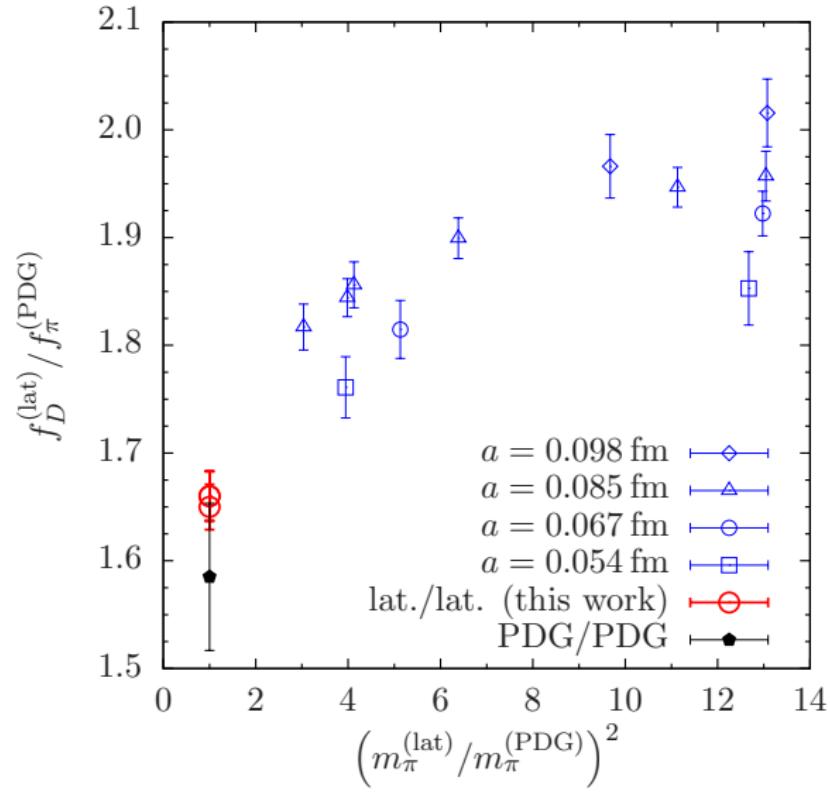


Pseudoscalar Meson Decay Constants

D meson decay constant

$$\frac{f_D}{f_\pi}$$

- old $N_f = 2$ data
- new $N_f = 2$ tm-clover
- Residual discrepancy probably signpost for discretization artefacts ($\sim 5\%$)

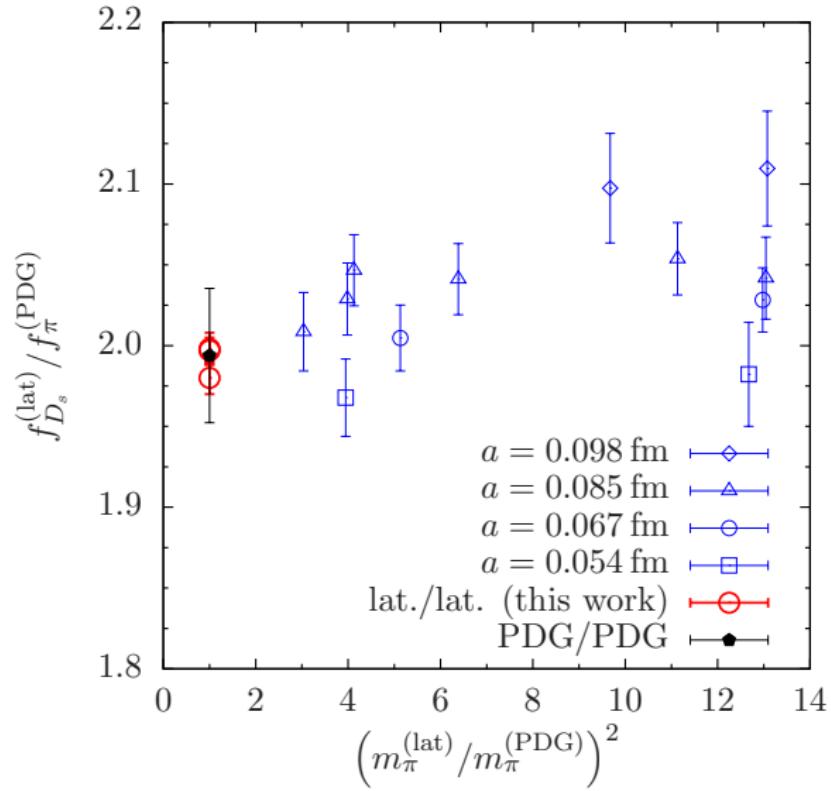


Pseudoscalar Meson Decay Constants

D_s meson decay constant

$$\frac{f_{D_s}}{f_\pi}$$

- old $N_f = 2$
- new $N_f = 2$
tm-clover
- without chiral extrapolation →
high statistical precision

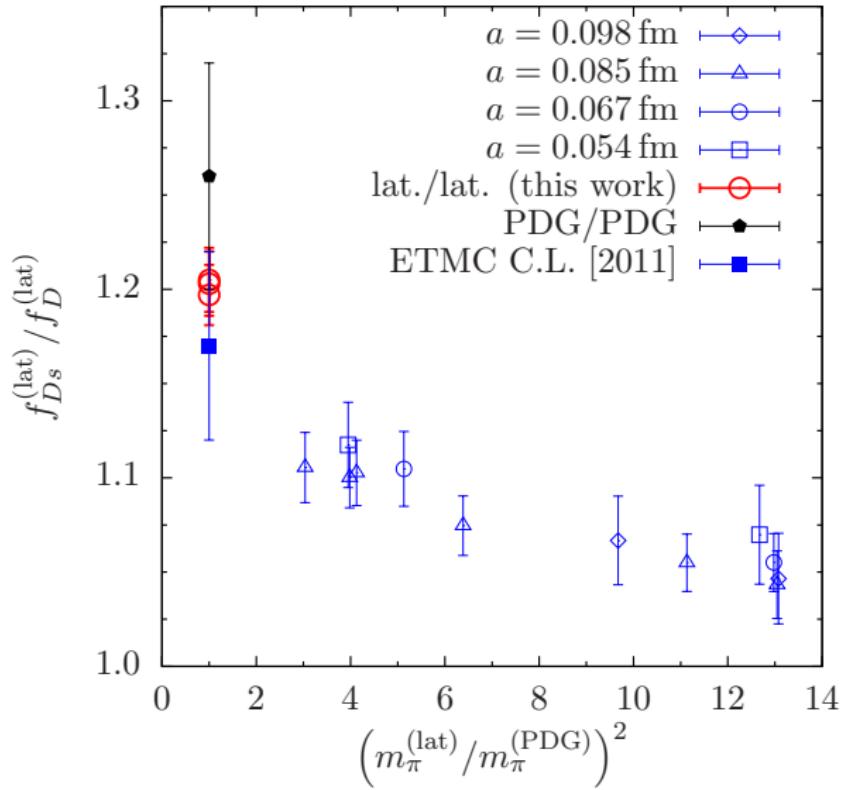


Pseudoscalar Meson Decay Constants

D_s and D meson decay constant ratio

$$\frac{f_{D_s}}{f_D}$$

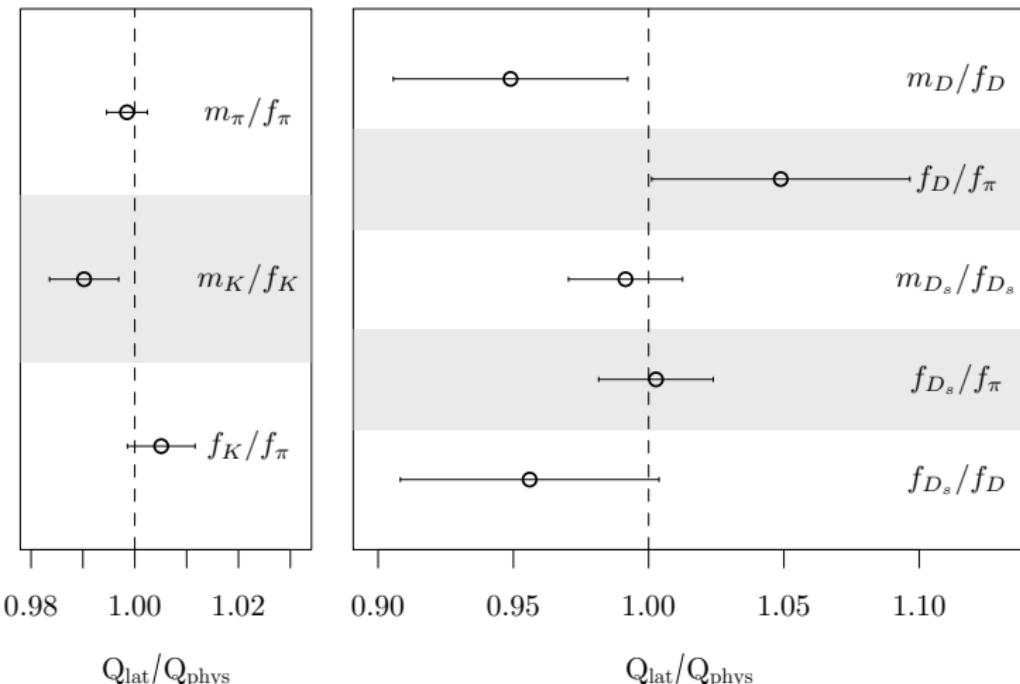
- old $N_f = 2$
- old $N_f = 2$ chiral extrapolation
- new $N_f = 2$ tm-clover
- good statistical precision
- → will allow for good study of discretization artefacts



Pseudoscalar Meson Decay Constants

Summary

- $Q_{\text{lat}} \div Q_{\text{phys}}$ for example: $Q_{\text{lat}} = \frac{m_{\pi}^{\text{lat}}}{f_{\pi}^{\text{lat}}}$ $Q_{\text{phys}} = \frac{m_{\pi}^{\text{phys}}}{f_{\pi}^{\text{phys}}}$
- Using μ_s and μ_c from m_K/m_{π} and m_D/m_{π} matching

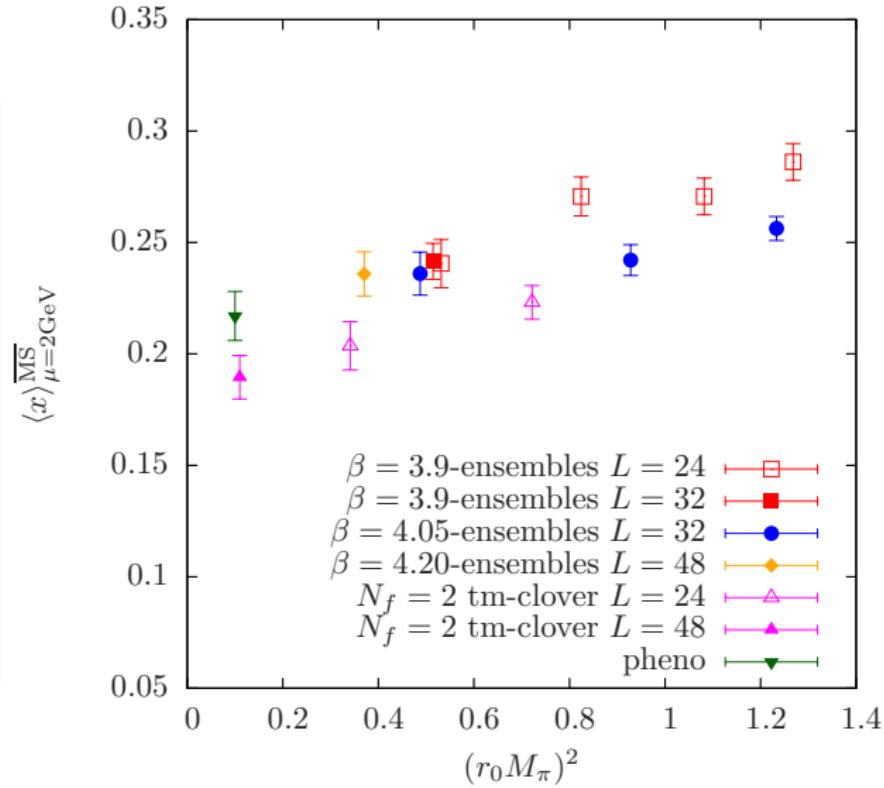


Preliminary Results

Pion $\langle x \rangle$

$\langle x \rangle_\pi$

- ▼ [nucl-ex/0702002]
- ▲ $N_f = 2$ tm-clover
- Opportunity for conclusive result in near future, but requires effort also on pheno. side to improve error analysis.

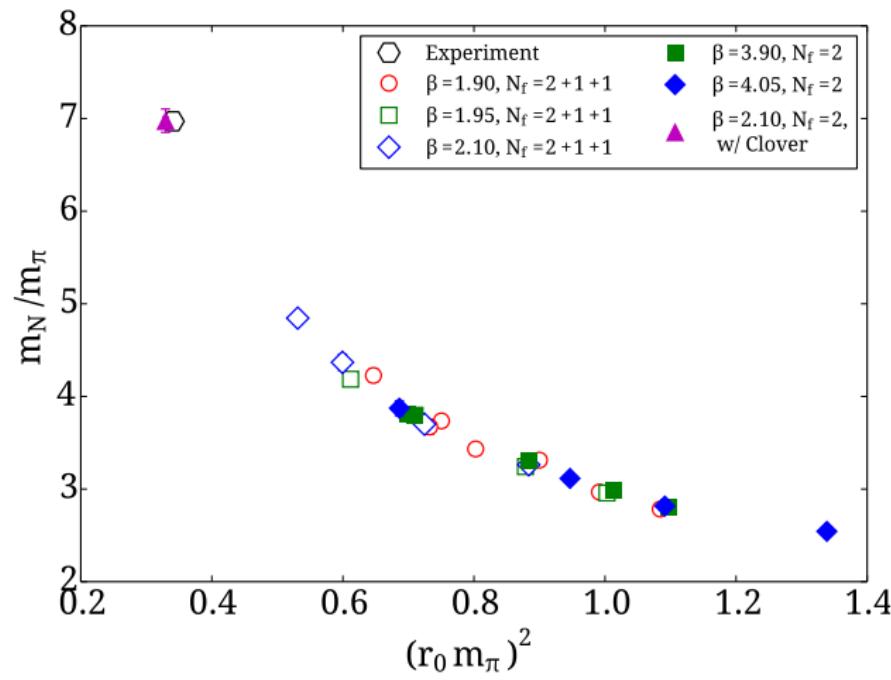


Preliminary Results

Nucleon mass

$$\frac{m_N}{m_\pi}$$

- Full consistency with experiment



Conclusion and Outlook

- $N_f = 2, \beta = 2.1, L_s = 48$: high statistics
- Quite confident that isospin splitting is small for pion, baryons
- Meson observables with high precision
- ⇒ with added systematics and continuum limit can pin down:
 - ▶ FS / lattice artefacts
 - ▶ strange/charm unquenching
- Seem to be at 2-5 % level depending on quantity
- $N_f = 2 + 1 + 1$ sea quark tuning OK with this kind of uncertainty
 - ⇒ At phys. point, use m_K/m_π and m_D/m_π as tuning condition
 - ⇒ Work ongoing, but certain aspects of tuning turned out to be more involved than expected
- Outlook
 - ▶ $N_f = 2$ continuum limit
 - ▶ $N_f = 2 + 1 + 1$